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# Design of An IOT-Based Voltage and Current Monitoring System and Turbine Performance Analysis In A Micro Hydro Power Plant

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*Abstract*

Microhydro power plants (MHPP) are a potential renewable energy solution for remote areas that have abundant water resources. However, monitoring the performance of MHPP systems in these areas is still a challenge, especially in terms of reliability and energy conversion efficiency. This research aims to design and develop an Internet of Things (IoT)-based monitoring system capable of monitoring real-time voltage and current in MHPs. The system was tested using the Archimedes Screw turbine in a laboratory-based test scale, and a literature study was conducted to compare the effectiveness of several types of micro hydro turbines such as Pelton, Crossflow, Turgo, and Archimedes Screw. The results showed that although the efficiency of screw turbines is relatively lower, they are suitable for use in locations with low head and stable water flow. The 4D approach method was used in the development of this monitoring system, and the results show that the system is able to provide accurate data and support the improvement of MHPP operational reliability.

## 1 Introduction

Microhydro Power Plant (MHPP) is a system that utilizes kinetic energy from the potential of water flow to be converted into electricity on a small scale, with a capacity below 100 kW [1]. This technology is a sustainable and environmentally friendly energy solution, especially for areas in remote areas that have not been reached by conventional electricity networks [2]. The advantage of Microhydro Power Plant (MHPP) lies in its ability to utilize local potential without the need for large-scale infrastructure, making it very suitable to be applied in rural and mountainous areas and contributing positively to the economic aspects of community welfare [3]. One of the crucial aspects in the successful implementation of a Microhydro Power Plant (MHPP) system is the selection of a turbine type that is suitable for the characteristics of the water flow at the location. The turbine acts as a converter of water energy into mechanical energy which is then converted into electrical energy through a generator. Several common types of turbines such as Pelton, Francis, Kaplan, and Cross-flow have their own characteristics in responding to head and water discharge conditions [4]. For example, Pelton turbines are suitable for high head and low discharge, while Kaplan is suitable for low head and high discharge. On the other hand, Cross-flow turbines are an alternative because of their simple design and flexibility to various flow conditions [5].



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However, although many turbines have been developed, the main challenge still lies in the optimal energy conversion efficiency in various geographical and hydrological conditions [6]. Therefore, innovations in turbine design in terms of shape, material, and flexibility continue to be developed to improve their performance and adaptability [7]. Some research has been done by developing screw turbines (Archimedes Screw) which offer high efficiency for low head and slow flow and are more environmentally friendly to aquatic ecosystems [8]. In addition to energy conversion efficiency, maintenance aspects and turbine durability against environmental conditions are also a concern. Water flow containing sediment particles can cause wear and corrosion, so material selection and surface coating technology become an important part of design innovation [9]. Considering Indonesia's diverse geographical conditions, a flexible and durable turbine is a key requirement to ensure the continuity and efficiency of the generation system.

On the other hand, to ensure the stability of electric power output and ease of operational monitoring, an Internet of Things (IoT)-based monitoring system is an important complement in today's Microhydro Power Plants (MHPP). The implementation of this monitoring system allows users to monitor voltage, current, and other operational conditions in real-time through an internet connection [10]. This not only improves operational management efficiency, but also enables early prediction of potential system disturbances [11].

Thus, this article aims to assess the effectiveness of different types of micro hydro turbines under various water flow conditions with relevant literature and design an Internet of Things (IoT)-based monitoring system that can support the operational efficiency of MHPP systems. This study contributes to answering the main question: "Which type of turbine is most optimally used under various water discharge and head conditions, and how can the monitoring system support its efficiency in monitoring voltage and current?". The structure of the article is organized as follows: Section 2 presents the classification and effectiveness of different types of micro hydro turbines based on mechanical and water flow characteristics. Section 3 discusses the implementation of the Internet of Things (IoT)-based voltage and current monitoring system design in Microhydro Power Plants (MHPP). Section 4 concludes the findings and practical implications of this study.

## 2 Design Characteristics and Type Selection of Microhydro Turbines

To understand the different types and design characteristics of micro hydro turbines, it is important to consider how they operate in converting the potential and kinetic energy of water into mechanical energy [12]. This analysis can include the shape of the blades, the number of blades, the rotation speed (RPM), the width of the turbine, the diameter of the turbine, such as the width and diameter of the runner, also affect the power capacity generated [13]. Furthermore, the influence of nozzle angle and position configuration also plays an important role in optimally directing water flow to the turbine blades [14]. Proper adjustment of nozzle angle can improve energy conversion efficiency by reducing energy loss due to turbulence or flow deviation [15]. By understanding and optimizing these parameters, turbine performance in Microhydro Power Plants (MHPs) can be improved, resulting in more optimal power output according to site characteristics and available water flow conditions [16]. Figure 1 which is adopted from "Directorate General of Electricity and Energy Utilization Book 2C in 2009 p.9, Figure 2 which is adopted from S.J. Williamson in 2011, and Table 1 shows the types of turbines in Microhydro Power Plants based on geographical conditions and power requirements in Microhydro Power Plants.

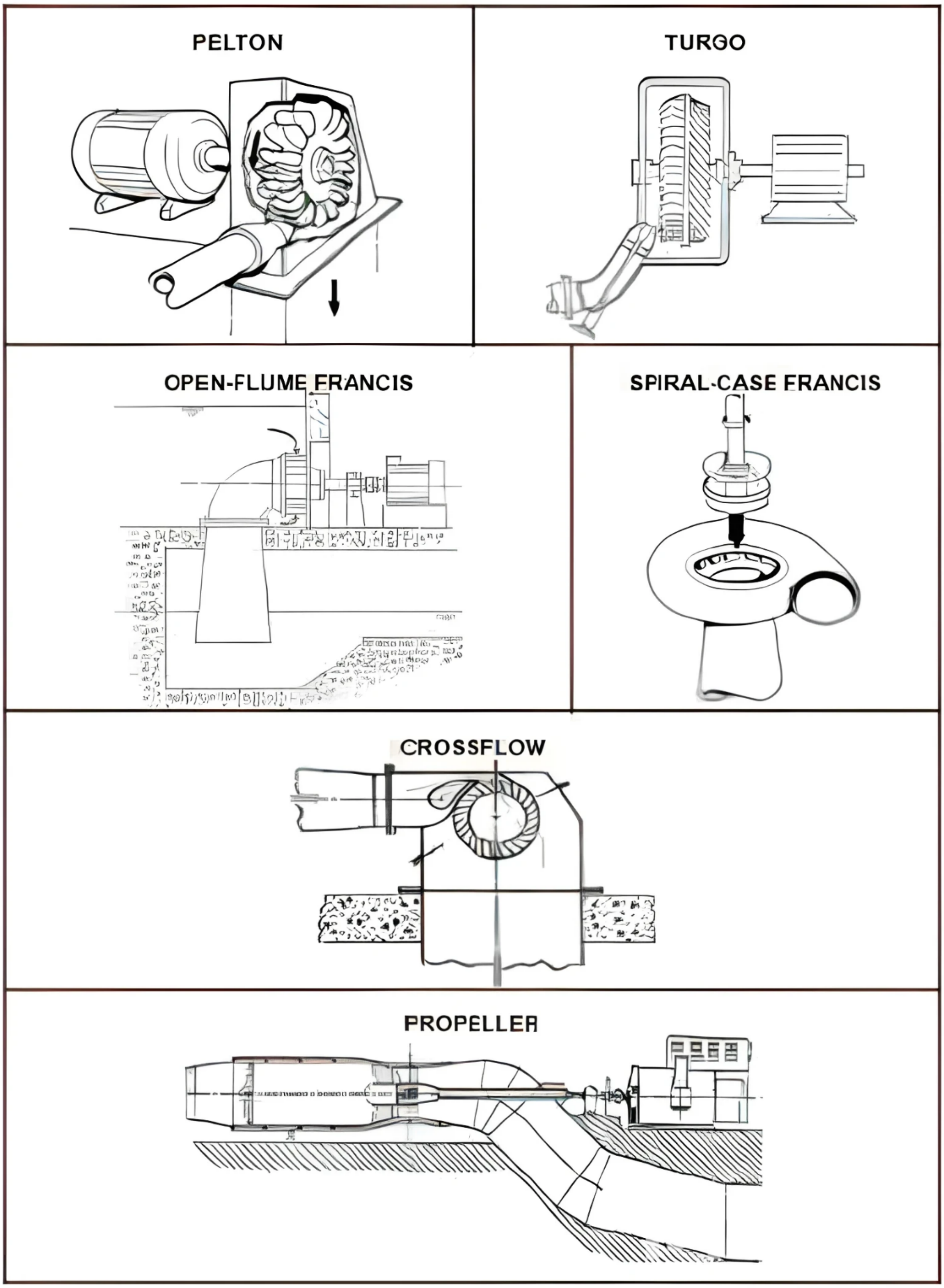


**Figure 1.** Turbine Type

**Table 1.** Type of Turbine

| Category | Turbine Type | | Characteristics | Water Head (Height) | Water Discharge |
|---|---|---|---|---|---|
| Based on Working Mechanism | Impulse Turbine (Water's kinetic energy drives the turbine blades without a change in pressure) | Pelton | Cup-shaped blades, suitable for high-pressure applications | >50 m | Low to Medium |
| | | Turgo | Smaller scoop than Pelton, higher rotation | 20–50 m | Medium |
| | | *Crossflow (Banki-Mitchell)* | Water passes through the blades in two stages, a simple design | 10–50 m | Medium |
| | Turbin Reaksi (Memanfaatkan tekanan air untuk menciptakan gaya reaksi) | Francis | Curved shaped blade, high efficiency | 10–100 m | Medium |
| | | Kaplan | The spoon can be adjusted to adjust the flow. | <20 m | large |
| | | Propeller | Similar to Kaplan, but with a fixed spoon. | <10 m | large |
| | | Archimedes Screw Turbine | Taking advantage of slow flow, suitable for shallow rivers | <10 m | large |
| Based on Water Fall Height (Head) | Low Head (<20 m) | Kaplan, Propeller, Ulir | Used for large debits | <20 m | large |
| | | *Crossflow* | Can be used for medium discharge | 10–50 m | Medium |
| | Medium Head (20–50 m) | Francis | Widely used in MHPP | 10–100 m | Medium |
| | | Turgo | High efficiency under moderate conditions | 20–50 m | Medium |
| | High Head (>50 m) | Pelton | Suitable for high pressure and small flow | >50 m | Low |
| | | Turgo | Smaller than Pelton, but higher speed | 20–50 m | Medium |
| Based on Water Flow Direction | Radial Flow (Water enters perpendicular to the turbine axis) | Francis | High efficiency, widely used | 10–100 m | Medium |
| | Mixed Flow (Combination of axial and radial flow) | Modifikasi Francis | The blades can be adjusted to suit the flow | 10–100 m | Medium |
| | *Crossflow* | *Crossflow (Banki-Mitchell)* | Simple design, easy to make | 10–50 m | Medium |

Source : [17]

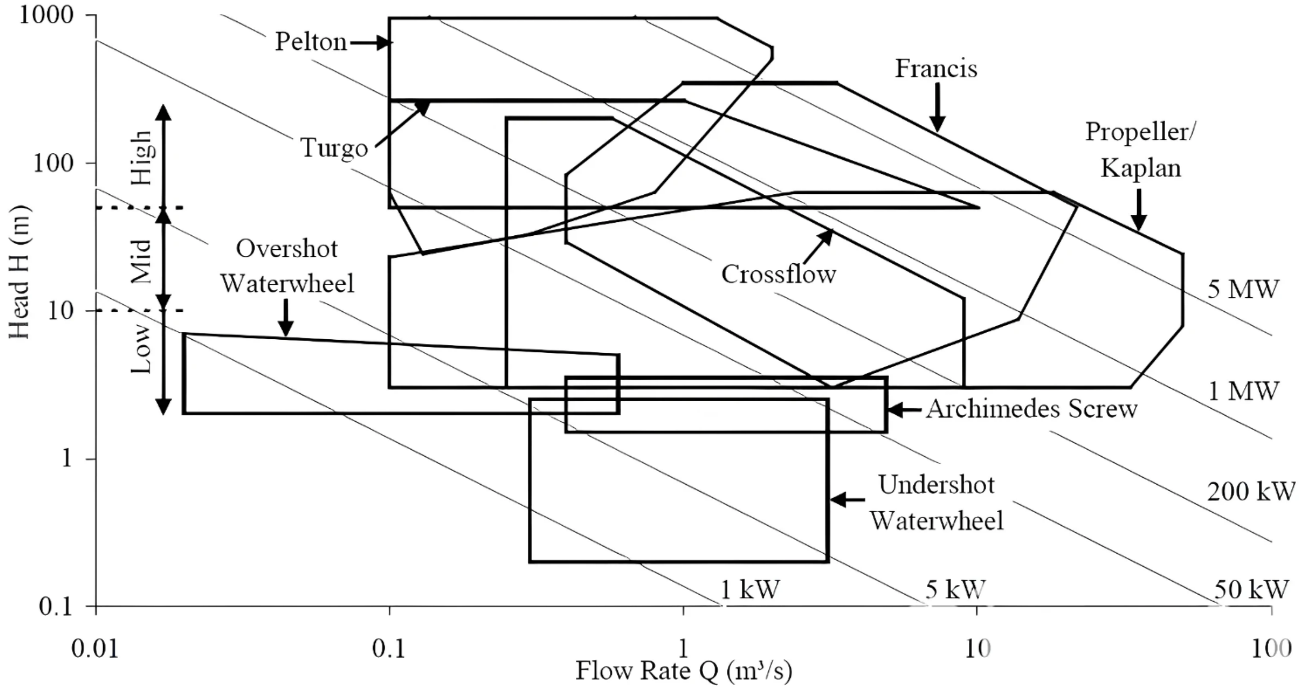


**Figure 2.** Selection of Tyrbine Type

## 2.1 Design and Selection of Water Turbine Types

The selection of turbine type in a micro-hydro system must consider the various advantages and limitations of each turbine type to suit the specific design required. In the early stages, this selection is made by taking into account a number of key parameters that affect turbine performance, as described by Dixon (1998), namely:

1. Effective Falling Height (Net Head) and water discharge

   This factor is a major determinant in the choice of turbine type. For example, Pelton Turbines are more suitable for large falling heights, while Propeller Turbines are more effectively used in low falling height conditions but with greater water discharge [18].
2. Desired Power

   The power that can be generated depends largely on the combination of the height of fall and the available water discharge. The higher these two factors, the greater the power that can be generated by the turbine [19].
3. Turbine Rotational Speed (n)

   This factor relates to how the power generated by the turbine can be transmitted to the generator [20]. For example, in a direct coupling system at low fall height, Propeller Turbines can achieve the desired rotation. In contrast, Pelton and Crossflow Turbines have lower revolutions, which can lead to a less than optimal system if not matched with an appropriate transmission mechanism.

The above three factors are often used to determine the specific speed of the turbine, which is one of the main references in turbine type selection. To ensure the suitability of the turbine to the operating conditions, a characteristic graph relating net falling height (m) and flow discharge ($m^3/s$) is usually used, as described by Penche & Minas (1998). The values of head and stream discharge can predict the power generated by the water to drive the turbine with the following equation 1.

$$P = \rho . Q . g . H \tag{1}$$

The equation is used to calculate the theoretical power generated by a water turbine. In this formula, P is the power (Watt), ρ is the density of water which is generally 1000 $kg/m^3$, Q is the water flow discharge in cubic meters per second ($m^3/s$), g is the acceleration of gravity which is 9.81 $m/s^2$, and H is the effective water fall height in meters (m). The specific speed of the turbine is also the basis for selecting the type of turbine because it will affect the transmission system to be used. The specific speed of the turbine is sought using the following equation 2.

$$n_s = n \frac{\sqrt{Q}}{H^{0,75}} \tag{2}$$

Equation 2 is used to determine the turbine specific speed (ns), which is an important parameter in the selection and design of water turbines [21]. In this formula, n is the turbine rotation speed in rotations per minute (rpm), Q is the water discharge flowing through the turbine in cubic meters per second ($m^3/s$), and H is the effective water fall height in meters (m). Turbine specific speed is a factor that describes the operational characteristics of the turbine based on the relationship between rotation speed, water flow discharge and falling height. Lower ns values are generally found in turbines used for large water drop heights, such as Pelton turbines, while higher ns values are generally found in turbines that work with low drop heights but with large water discharge, such as Kaplan or Propeller turbines [22]. Turbine specific speed table in table 2 as follows.

**Table 2.** Turbine Specific Speed

| Turbine Type | Specific Speed | Reference |
|---|---|---|
| Pelton (1 jet) | $Ns=85.49/H^{0.243}$ | Siervo & Lugaresi (1978) |
| Francis | $Ns=3763/H^{0.854}$ | Schweiger & Gregory (1989) |
| Kaplan | $Ns=2283/H^{0.486}$ | Schweiger & Gregory (1989) |
| Crossflow | $Ns=513.25/H^{0.505}$ | Kpordze & Wamick (1983) |
| Propeller | $Ns=2702/H^{0.5}$ | USBR (1976) |

Source : [23]

## 2.2 Design and Selection of Water Turbine Types

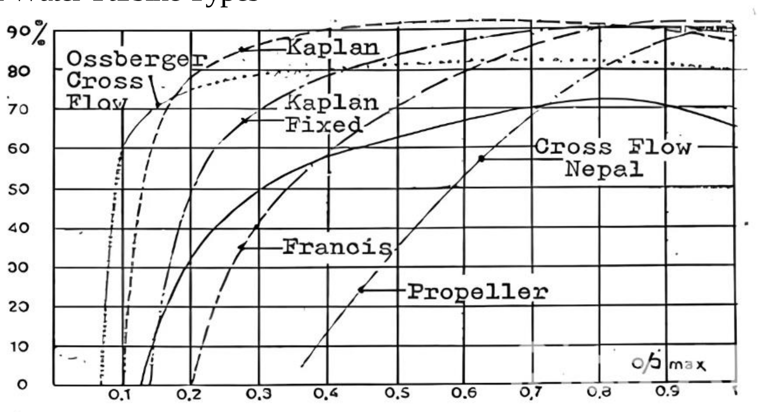


**Figure 3.** Turbine efficiency diagram

This diagram on Figure 3 was adopted from Barglazan in 2005 shows the relationship between the efficiency of various types of water turbines and the ratio of discharge to maximum discharge (Q/Qmax)

[24]. The vertical axis represents the efficiency in percent (%), while the horizontal axis shows the ratio of discharge to maximum discharge. From the diagram, it can be seen that the Ossberger Cross Flow turbine has a relatively high efficiency in the low discharge range. The Kaplan and Kaplan Fixed turbines show high and stable efficiency over a wide range of discharge variations, with the best performance at larger discharge ratios. Francis turbines have fairly good efficiency but tend to be lower than Kaplan turbines. Meanwhile, the Propeller turbine has a lower efficiency than the other types and shows an increase in efficiency as the discharge increases. The Cross Flow Nepal turbine shows unique characteristics with efficiency increasing as the discharge increases until it reaches its optimum point.

This shows that these turbines can be a good choice for fluctuating discharge conditions, especially in areas that experience seasonal variations in water flow. In addition, from this diagram it can be concluded that turbines with high efficiency at various discharge ratios, such as Kaplan and Kaplan Fixed, are more suitable for power generation systems that require long-term operational stability. In contrast, turbines such as Cross Flow and Ossberger are more flexible in the face of changes in discharge, so they are often used for small-scale projects or remote areas [25]. Overall, this diagram illustrates how each turbine type has different efficiency characteristics depending on the available water discharge, so turbine selection should consider the appropriate operational conditions.

## 3 Implementation of Internet of Things (IoT) Based Current Voltage Monitoring System

The application of an Internet of Things (IoT)-based monitoring system in Microhydro Power Plants (MHPP) is a significant urgency in answering the challenges of efficiency and reliability of renewable energy system operations in remote areas. Real-time monitoring of voltage and current enables operational monitoring of Microhydro Power Plants (MHPP). This is particularly relevant given that Micro Hydro Power Plants (MHPP) often operate without direct supervision and are vulnerable to load fluctuations and environmental conditions. With an Internet of Things (IoT) based system, operators can remotely monitor system performance continuously, so that potential damage can be minimized and continuity of electricity supply maintained.

### 3.1 Research Methods

This research uses a Research and Development (R&D) approach with the 4D development model (Define, Design, Develop, and Disseminate) which is focused on designing and implementing an Internet of Things (IoT)-based voltage and current monitoring system on a laboratory-scale Microhydro Power Plant (MHPP). The development process starts from defining the analysis of system needs and plant characteristics, followed by schematic design and design of monitoring devices using PZEM-004T sensors and ESP32 microcontrollers and other complementary modules. After the system was assembled and integrated with a remote monitoring platform (Blynk), a series of simulation tests were conducted to ensure the performance of the device. Other tests include aspects of system functionality, feasibility of the device when used in operational conditions, real-time measurement of voltage and current values. The data obtained is used as a reference to evaluate the accuracy of the system compared to manual measurements using a multimeter. In the provisions indicated that the system must be able to record data with a low error rate below 5%. This indicates that the monitoring system developed has good reliability in supporting the operation of small-scale power plants. The following is a diagram of the design of an Internet of Things (IoT)-based voltage and current monitoring system in a Microhydro Power Plant (MHPP).

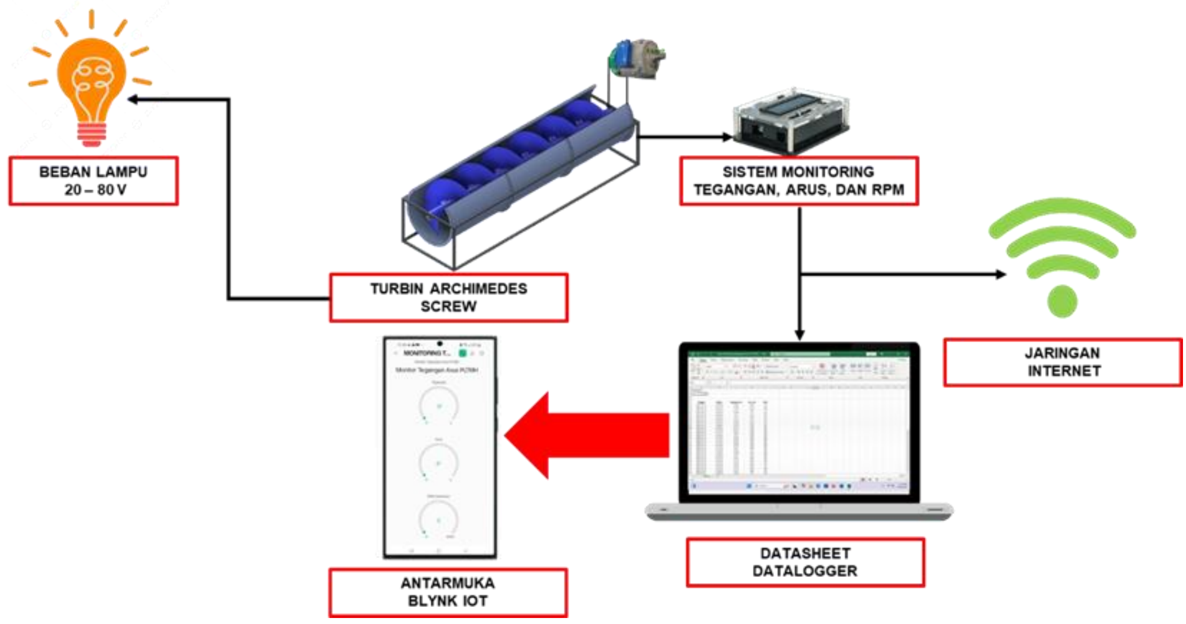


**Figure 4.** Diagram of the Internet of Things (IoT)-based Voltage and Current Monitoring System Design for Microhydro Power Plants (MHPP)

## 3.1 Result and Discussion

The research results begin with the stage of defining aspects of the monitoring system needs, which includes identifying the main electrical parameters such as voltage and current that need to be monitored in real-time in the design of the monitoring system at the Microhydro Power Plant (MHP). The schematic design of the voltage and current monitoring system is shown in Figure 5 below.

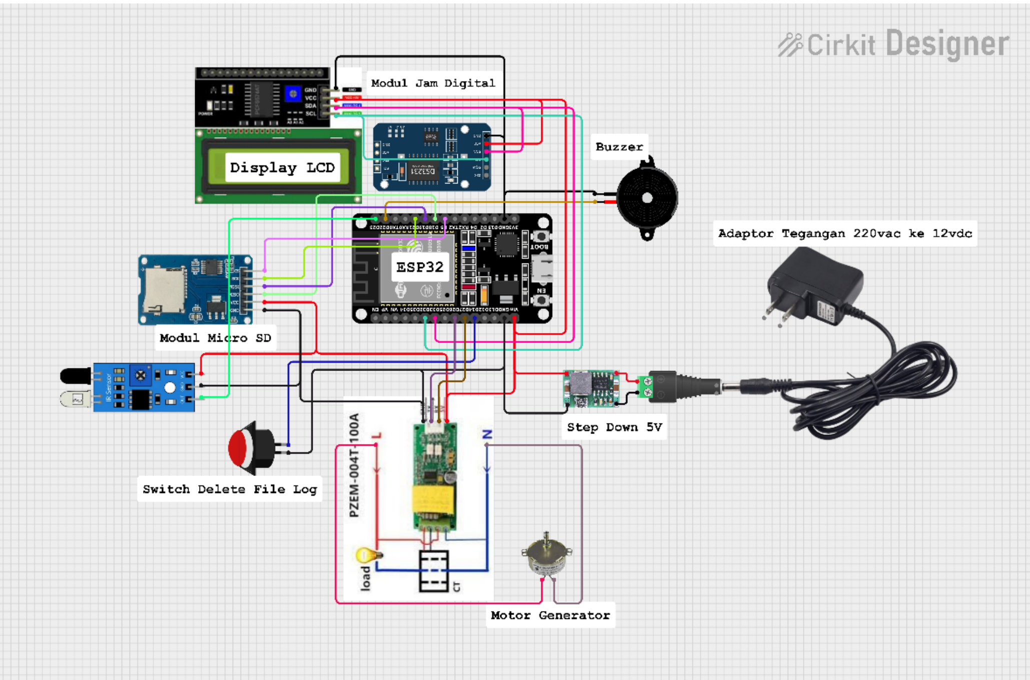


**Figure 5**. Schematic Design of Monitoring System

Table 3 below describes the aspects of the needs of the Internet of Things (IoT)-based voltage and current monitoring system at the Microhydro Power Plant. The next stage is to design the schematic design of the monitoring system. This design describes the relationship between components such as the PZEM-004T sensor, ESP32 microcontroller, DS3231 RTC, MicroSD module, LCD, buzzer, and switch. All components are connected through signal lines and customized power using step-down and 12V-5V adapters. This schematic becomes a reference in the physical assembly process so that the system works according to the designed function. This schematic design is prepared using Cirkit Designer software which simplifies the integration process and minimizes the risk of circuit errors during physical implementation. The following is the schematic design of the Internet of Things (IoT)-based voltage and current monitoring system design for the Microhydro Power Plant.

**Table 3.** Aspects of Monitoring System Needs

| No | Neeeds Aspect | Component Type | Main Function |
|---|---|---|---|
| 1 | Voltage and Current Sensors | PZEM-004T 100A | Measure voltage and current in real-time |
| 2 | Microcontroller | ESP32 | Process data and send to Internet of Things (IoT) platform |
| 3 | MicroSD Modul | Micro SD Module | Menyimpan log data hasil pemantauan |
| 4 | Switch Delete File Log | Push On Button R13-507 | Save the monitoring result data log |
| 5 | Digital Clock Module (RTC) | DS3231 SN + IC AT24C32 | Provides real-time for data time stamping |
| 6 | Speed Module | Speed Sensor | Monitor system speed |
| 7 | Resistor | Resistors (variety as needed) | Adjust the current to match the circuit specifications |
| 8 | Buzzer | Buzzer Piezoelectric | Memberi notifikasi suara ketika sistem terhubung |
| 9 | Step Down 5V | MP1584 Step Down DC 3A | Reduce voltage from 12V to 5V |
| 10 | LCD Display | LCD 2x16 | Displays voltage, current, RPM data directly |
| 11 | Adaptor 12V to 5V | Adaptor DC | Converts power from 12V to 5V for the system |
| 12 | Internet of Things (IoT) Platforms | Blynk App | View and control the system remotely via smartphone |

Based on the schematic design that has been prepared, the next process is to realize the design into physical form. This stage includes the preparation and assembly of all components into an integrated circuit, according to the connection scheme that has been designed previously. The goal is to ensure that the system can run for real and is ready to be tested for functionality and performance. During the assembly process, trial tests are performed to ensure that no components have technical problems. All modules were connected according to the predetermined communication and power supply lines. Each connection was tested with a multimeter to verify the continuity and stability of the voltage and current. After everything is connected, the system is turned on to see if the program runs as instructed and the data displays on the LCD and Blynk interface. The figure 6 is the physical circuit of the Internet of Things (IoT)-based voltage and current monitoring system for Microhydro Power Plant (MHPP).

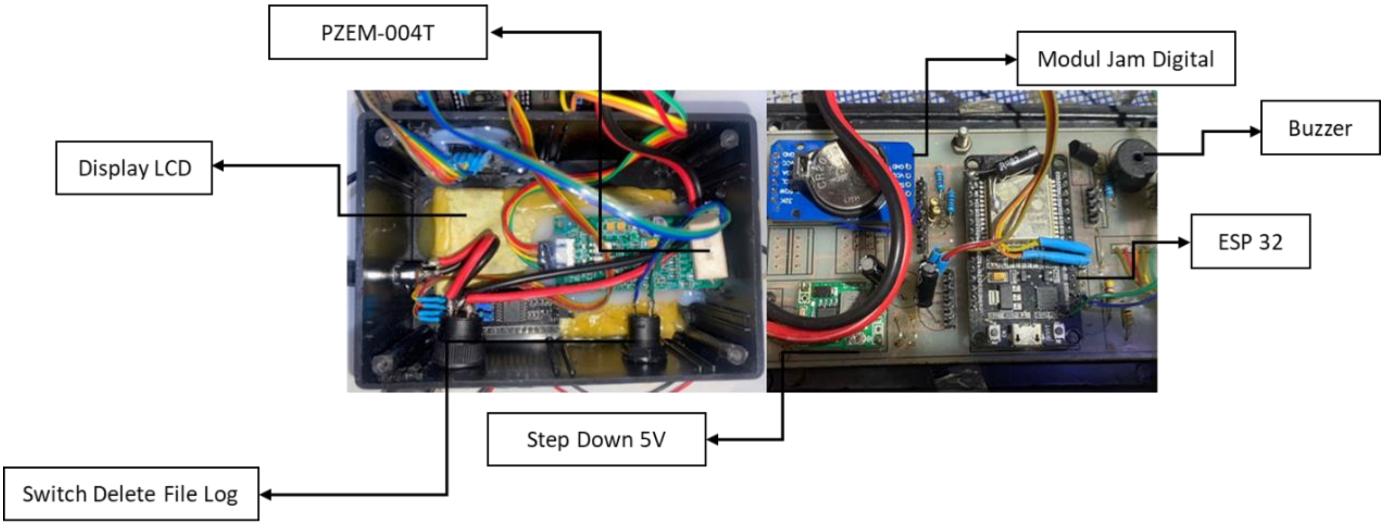


**Figure 2.** Physical Circuit of Internet of Things (IoT) Based Voltage and Current Monitoring System in Micro Hydro Power Plant (MHPP)

### 3.2.1 Monitoring System Simulation Testing

Simulation test results on the Internet of Things (IoT)-based voltage and current monitoring system show that all hardware and software components have functioned properly. Hardware validation confirms that connections between components, such as ESP32, PZEM-004T sensor, Micro SD Module, and LCD, as well as other modules work without errors. ESP32 program testing also found no problems in the code verification process. In addition, the PZEM-004T sensor successfully provides voltage and current readings with an accuracy level that meets the standards (<5% error). The speed module also showed stable RPM measurement results, while the digital clock module ensured that the logging time was in accordance with real-time. Testing additional features, such as the Log File Delete Switch and data storage on the MicroSD Module, proved that data can be managed properly without losing important information. In the Internet of Things (IoT) system test, the ESP32 successfully connected to the Arduino IDE without any problems, and the PZEM-004T sensor was able to transmit voltage and current data accurately. The stability of the Internet of Things (IoT) system is tested by ensuring real-time data transmission through the Blynk platform, which shows a latency time of less than 5 seconds, as per the standard. Log files can be deleted via the switch, and data is well stored on the MicroSD Module without errors. In addition, the data display on the Blynk dashboard is always updated in real-time. Overall, the system has shown stable performance and is ready to be implemented on a larger scale.

### 3.2.2 Tool Suitability Testing

Based on the results of testing the feasibility aspects that have been carried out, the Internet of Things (IoT)-based voltage and current monitoring system at the Microhydro Power Plant (MHP) has shown good performance in aspects of technical feasibility, system capability, security, and implementation effectiveness. Hardware and software validation showed that all components functioned properly without any significant errors. Testing of the PZEM-004T sensor also proved that the system has a high level of accuracy in reading voltage and current, with errors below 5%. In addition, the stability of the system was tested within a certain operational time, showing that the system runs continuously without interruption. The Internet of Things (IoT) interface data transmission on Blynk performed well, with a latency of less than 5 seconds, ensuring real-time data can be accessed without significant delay. The following tables 4 and 5 show the assessment results of the tool feasibility test and the assessment of each aspect.

**Table 4.** Assessment of Equipment Feasibility Test Results

| Validator | ∑Skor | ∑Skor Max | Average Score Per Item | Percentage (%) | Category |
|---|---|---|---|---|---|
| 1 | 48 | 50 | 3.84 | 96% | Very High |
| 2 | 47 | 50 | 3.76 | 94% | Very High |
| 3 | 47 | 50 | 3.76 | 94% | Very High |
| Average | 47,33 | 50 | 3.78 | 94,7% | Very High |

**Table 5.** Assessment of Each Aspect

| Aspects | Total Score per Aspect | Skor Max | Average Per Aspect | Percentage (%) | Category |
|---|---|---|---|---|---|
| Tool Qualification | 42 | 45 | 3.73 | 93,3% | Very High |
| System Capabilities | 29 | 30 | 3.86 | 96,7% | Very High |
| Security Reliability | 28 | 30 | 3.73 | 93,3% | Very High |
| Implementation Effectiveness | 43 | 45 | 3.82 | 95,6% | Very High |

The assessment conducted by three expert practitioners indicates that the system is deemed feasible, with an average evaluation score reaching 94.7%, categorized as “very high” or “excellent.” All evaluated aspects—including technical feasibility (93.3%), system capability (96.7%), safety and reliability (93.3%), and implementation effectiveness (95.6%)—achieved outstanding scores. Based on these results, it can be concluded that the system is not only feasible for use but also reliable as a voltage and current monitoring solution for Micro-Hydro Power Plants (MHPP) based on the Internet of Things (IoT), with strong potential for implementation in small to medium-scale power generation systems.

### 3.2.3 Functionality Testing

The voltage and current monitoring system based on the Internet of Things (IoT) for Micro-Hydro Power Plants (MHPP) functions in accordance with user functionality requirements. Testing conducted by three expert practitioners demonstrated that the system successfully fulfilled all aspects of functionality based on the ISO/IEC 9126 standard, including suitability, accuracy, interoperability, compliance, and security. Using the black box testing method, the evaluation focused on system outputs to ensure that each feature operated correctly. The test results indicated a very high level of success, meaning that the system met all criteria for functionality feasibility and is reliable for real-time voltage and current monitoring. The system’s success in fulfilling the functionality aspect indicates that both the design and laboratory-scale testing adhered to the expected specifications. This suggests that the system is capable of meeting user needs with a high degree of accuracy and can be seamlessly integrated into broader systems. Therefore, the system is not only feasible for small-scale implementation but also holds significant potential for further development in larger-scale industrial applications.

### 3.2.4 Measurement Testing

At this stage, the voltage and current monitoring system based on the Internet of Things (IoT) for the Micro-Hydro Power Plant (MHPP) was implemented to record data in real-time. In this test, a 10-watt lamp was used as the load, serving to absorb the electrical power generated by the plant and providing a basis for testing the voltage and current sensors. The lamp represents a resistive load, which is ideal for simply observing the monitoring system's performance under real operating conditions. The data logger display in the Excel application is shown in Tables 6 and 7, accompanied by Graphs 7 and 8.

**Table 6.** First Voltage Measurement in the Monitoring System

| Waktu | RPM | Multimeter (V) | *Blynk* (V) | Selisih (V) | *Error* (%) |
|---|---|---|---|---|---|
| 8:00:00 | 362 | 33.8 | 33.86 | 0.06 | 0.17 |
| 8:05:00 | 374 | 33.8 | 33.83 | 0.03 | 0.08 |
| 8:10:00 | 358 | 33.7 | 33.77 | 0.07 | 0.20 |
| 8:15:00 | 391 | 33.9 | 33.91 | 0.01 | 0.02 |
| 8:20:00 | 367 | 33.8 | 33.87 | 0.07 | 0.20 |
| 8:25:00 | 380 | 33.8 | 33.86 | 0.06 | 0.17 |
| 8:30:00 | 355 | 33.7 | 33.78 | 0.08 | 0.23 |
| 8:35:00 | 398 | 33.9 | 33.91 | 0.01 | 0.02 |
| 8:40:00 | 371 | 33.8 | 33.89 | 0.09 | 0.26 |
| 8:45:00 | 386 | 33.9 | 34 | 0.1 | 0.29 |
| Rata – Rata Error | | | | | 0.16 |

**Table 7.** Second Voltage Measurement in the Monitoring System

| Waktu | RPM | Multimeter (V) | *Blynk* (V) | Selisih (V) | *Error* (%) |
|---|---|---|---|---|---|
| 9:00:00 | 352 | 33.7 | 33.75 | 0.05 | 0.14 |
| 9:05:00 | 365 | 33.8 | 33.85 | 0.05 | 0.14 |
| 9:10:00 | 358 | 33.7 | 33.78 | 0.08 | 0.23 |
| 9:15:00 | 372 | 33.9 | 33.95 | 0.05 | 0.14 |
| 9:20:00 | 368 | 33.8 | 33.86 | 0.06 | 0.17 |
| 9:25:00 | 359 | 33.7 | 33.75 | 0.05 | 0.14 |
| 9:30:00 | 380 | 34 | 34.07 | 0.07 | 0.20 |
| 9:35:00 | 354 | 33.7 | 33.76 | 0.06 | 0.17 |
| 9:40:00 | 366 | 33.8 | 33.88 | 0.08 | 0.23 |
| 9:45:00 | 402 | 34.2 | 34.3 | 0.1 | 0.29 |
| Rata – Rata Error | | | | | 0.18 |

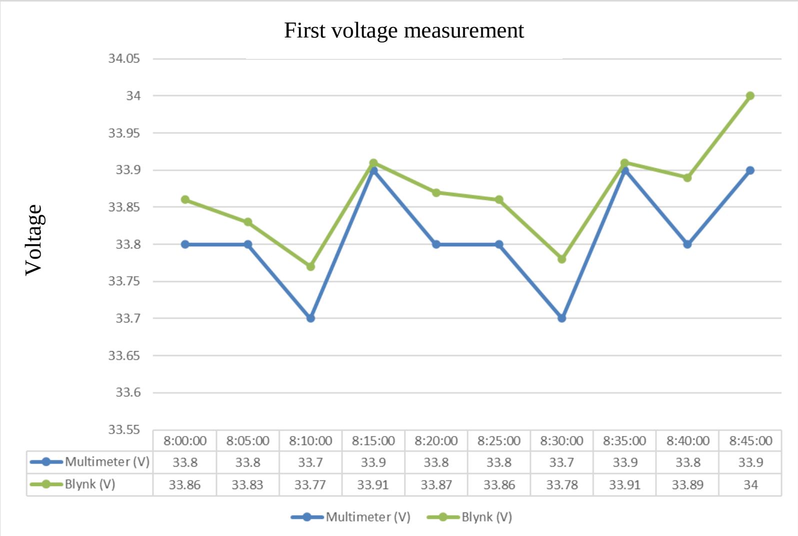


**Figure 7**. First Voltage Test Graph of the Monitoring System

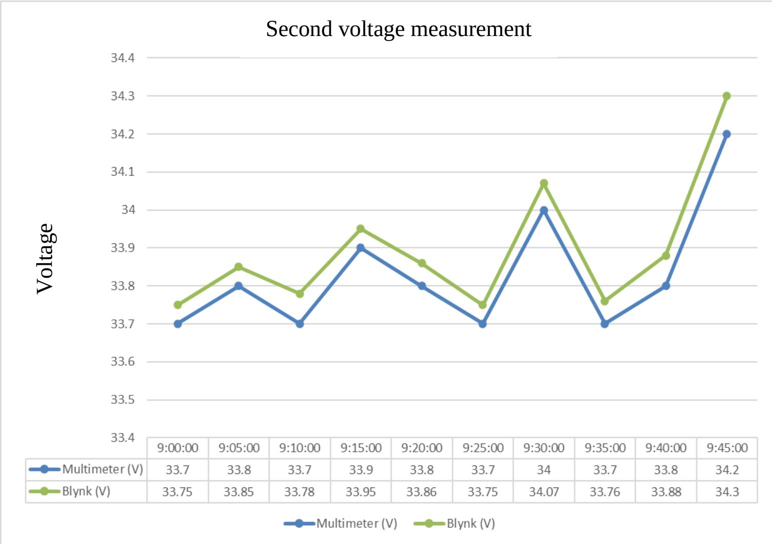


**Figure 8**. Second Voltage Test Graph of the Monitoring System

` This analysis confirms the reliability of the monitoring system in measuring electrical parameters in a Micro-Hydro Power Plant (MHPP). Voltage error values were low 0.16% in the first test and 0.18% in the second with accuracy rates of 99.84% and 99.82%, meeting the standard error threshold of less than 5%. Current measurements, conducted similarly, are shown in Tables 8 and 9 and Graphs 9 and 10 to evaluate real-time data performance.

**Table 7.** Second Voltage Measurement in the Monitoring System

| Waktu | RPM | Multimeter (A) | *Blynk* (A) | Selisih (A) | *Error* (%) |
|---|---|---|---|---|---|
| 8:00:00 | 362 | 0.3 | 0.3 | 0 | 0 |
| 8:05:00 | 374 | 0.3 | 0.31 | 0.01 | 3.33 |
| 8:10:00 | 358 | 0.28 | 0.29 | 0.01 | 3.57 |
| 8:15:00 | 391 | 0.3 | 0.31 | 0.01 | 3.33 |
| 8:20:00 | 367 | 0.29 | 0.3 | 0.01 | 3.44 |
| 8:25:00 | 380 | 0.3 | 0.31 | 0.01 | 3.33 |
| 8:30:00 | 355 | 0.28 | 0.28 | 0 | 0 |
| 8:35:00 | 398 | 0.3 | 0.31 | 0.01 | 3.33 |
| 8:40:00 | 371 | 0.29 | 0.3 | 0.01 | 3.44 |
| 8:45:00 | 386 | 0.3 | 0.31 | 0.01 | 3.33 |
| Rata – rata Error | | | | | 2.64 |

**Table 7.** Second Voltage Measurement in the Monitoring System

| Waktu | RPM | Multimeter (A) | *Blynk* (A) | Selisih (A) | *Error* (%) |
|---|---|---|---|---|---|
| 9:00:00 | 352 | 0.28 | 0.29 | 0.01 | 3.57 |
| 9:05:00 | 365 | 0.3 | 0.31 | 0.01 | 3.33 |
| 9:10:00 | 358 | 0.29 | 0.3 | 0.01 | 3.44 |
| 9:15:00 | 372 | 0.3 | 0.31 | 0.01 | 3.33 |
| 9:20:00 | 368 | 0.3 | 0.3 | 0 | 0 |
| 9:25:00 | 359 | 0.29 | 0.29 | 0 | 0 |
| 9:30:00 | 380 | 0.3 | 0.31 | 0.01 | 3.33 |
| 9:35:00 | 354 | 0.29 | 0.3 | 0.01 | 3.44 |
| 9:40:00 | 366 | 0.29 | 0.3 | 0.01 | 3.44 |
| 9:45:00 | 402 | 0.3 | 0.31 | 0.01 | 3.33 |

| | |
|---|---|
| Rata - Rata Error | 2.65 |

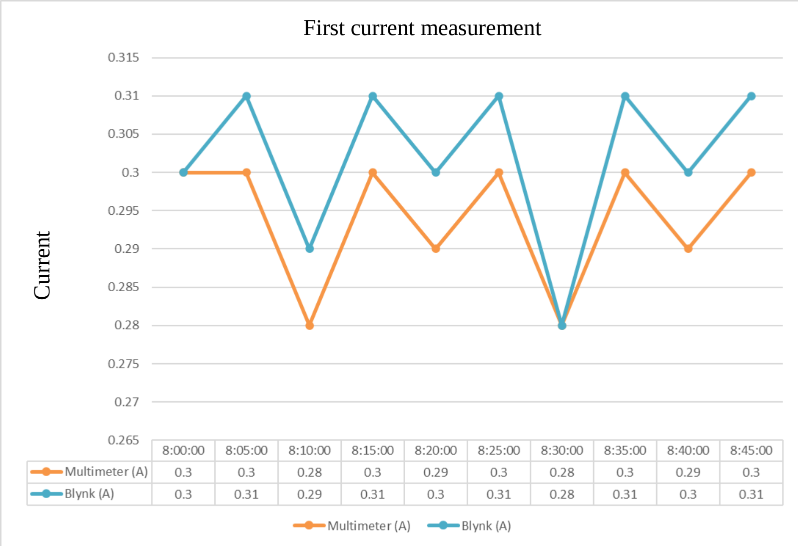


**Figure 9**. First Current Test Graph of the Monitoring System

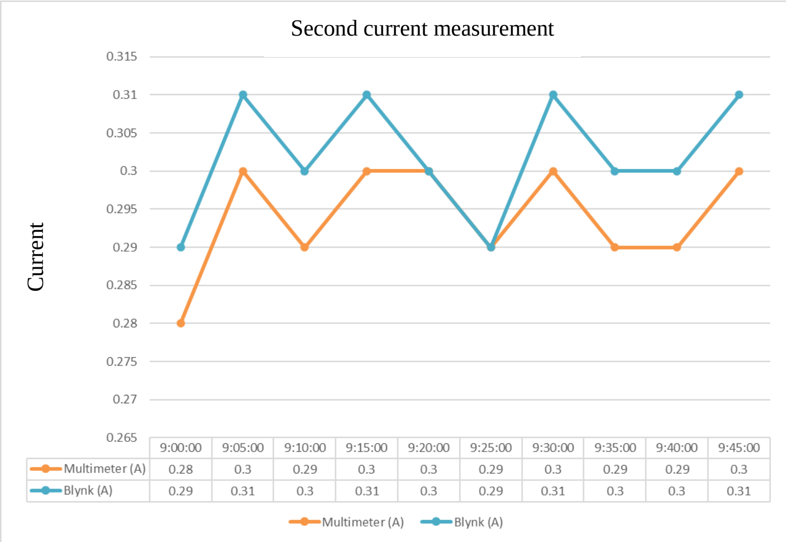


**Figure 10**. Second Current Test Graph of the Monitoring System

This study recorded low current measurement error values, namely 2.64% for the first test and 2.65% for the second, with corresponding accuracy levels of 97.36% and 97.35%. Therefore, the results meet the standard threshold of less than 5% error. In this research, electrical power was calculated based on voltage and current readings obtained from the IoT-based monitoring system and compared with conventional measurements using a multimeter. In the first test, power measured using the multimeter ranged from 10.14 W to 10.17 W, while the Blynk system recorded values ranging from 10.15 W to 10.54 W. In the second test, the multimeter readings ranged from 10.11 W to 10.26 W, while Blynk results ranged from 10.12 W to 10.63 W. Additionally, the recorded RPM error in the first and second tests were 0.26% and 0.33%, respectively. The small discrepancies and consistent measurement patterns indicate that the system is capable of recording electrical power with high accuracy.

## 4 Conclusion

Based on the study of various types of micro-hydro turbines, selecting the appropriate turbine highly depends on technical factors such as the head (water fall height), flow rate, efficiency, and the turbine's specific speed. Each turbine type has its own advantages according to the site characteristics. On the other hand, the success of implementing a voltage and current monitoring system based on the Internet of Things (IoT) in a Micro-Hydro Power Plant (MHPP) is also greatly influenced by the stability and characteristics of the turbine used. Therefore, choosing the right turbine type not only supports power generation optimization but also ensures the accuracy and stability of the data monitored through the system. The conclusions of this study are as follows:

1. The Crossflow turbine is recommended for locations with medium head and fluctuating flow rates, while the Archimedes screw turbine is more suitable for locations with low head and large, stable flow rates. The final choice depends on the topographic conditions and water potential at the MHPP site.
2. The voltage monitoring system based on the Internet of Things (IoT) in the Micro-Hydro Power Plant (MHPP) was successfully developed by integrating the PZEM-004T sensor, ESP32 microcontroller, and the Blynk platform. This system is capable of monitoring voltage in real-time with high accuracy, as demonstrated by test results showing very low error rates of 0.16% and 0.18%.
3. The IoT-based current monitoring system was also successfully built and implemented, with automatic current data transmission to the Blynk platform. Test results show the system can record current with good accuracy, with error values of 2.64% and 2.65%, respectively.
4. The monitoring system is equipped with a data logger feature based on a MicroSD module and DS3231 RTC for automatic real-time recording of voltage, current, and power. Test results indicate a very small difference in power readings between the multi-meter and Blynk, with an average RPM error below 0.5%, indicating high system accuracy and reliability. Using the PZEM-004T sensor, the system can theoretically monitor power up to 22,000 Watts, although the prototype only recorded up to 500 Watts in line with the generator's capacity. The system also passed the feasibility test based on the ISO/IEC 9126 standard with a score of 94.7% from expert practitioners.

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